64-12

URS 638-2

STUDY OF FACTORS INFLUENCING REMEDIAL MOVEMENT

Myron B Hawkins

17 April 1964

Submitted to
Office of Civil Defense
Department of Defense
Contract No. OCD-PS-64-20
OCD Subtask No. 3221A

URS
UNITED RESEARCH SERVICES

URS 638-2

STUDY OF FACTORS INFLUENCING REMEDIAL MOVEMENT

17 April 1964

This report has been reviewed in the Office of Civil Defense, Department of Defense and approved for publication. Approval does not signify that the contents necessarily reflect the view and policies of the Office of Civil Defense.

by

Myron B Hawkins
URS
1811 Trousdale Drive
Burlingame, California

Submitted to
Office of Civil Defense
Department of Defense
Contract No. OCD-PS-64-20
OCD Subtask No. 3221A

FOREWORD

The material for this report was first prepared in 1961 when the author was an employee of the Institute of Engineering Research of the University of California. The work was performed as part of an Office of Civil Defense and Mibilization contract that concerned investigations of radiological defense operations. A review of the available literature on peripheral countermeasures confirmed the author's view that with a slight revision and clarification of the material, this report provided a contribution to the knowledge in the general subject area, and a wider distribution of the information was desirable. Mr. William J. Lacy, the Office of Civil Defense Project Coordinator, has concurred.

ABSTRACT

The feasibility of remedial movement, i.e., transfer of people from inadequate fallout shelters to areas providing greater protection, was investigated. The study took into account fallout arrival time, reference radiation intensity, shelter or refuge protective factor, and travel time. Primary payoff conditions were defined in terms of reduction of radiation casualties.

Within the limitations imposed by the conditions of the study, certain general conclusions were drawn:

1. As might be expected, the maximum opportunities for payoff are related to refuges having lower protection factors, i.e., less than 10.

2. Maximum payoff conditions are related to fallout arriving at early times.

3. Maximum payoff conditions generally involve reference radiation intensities of 350 r/hr or greater, with the upper limit of about 2000 r/hr.

4. For one-hour arrivals (i.e., when fallout arrives at about one hour after detonation), the maximum allowable travel time for maximum payoff is about 1.3 hours.

TABLE OF CONTENTS

LIST OF FIGURES

List of Figures (Cont'd)

LIST OF TABLES

STUDY OF FACTORS INFLUENCING REMEDIAL MOVEMENT

INTRODUCTION

One of the measures suggested for the reduction of fallout radiation casualties is postattack remedial movement1/. This countermeasure is defined as the transfer of people from "refuges" (areas where fallout radiation protection is less than a factor of 100) to areas providing greater protection. The movement would be performed in the period following fallout deposition and its object would be to reduce the radiation hazard to those persons not having adequate protection. The purpose of this study is to investigate and designate those radiological and operational situations for which remedial movement is technically feasible and worthwhile, as well as those situations in which remedial movement is unnecessary or unprofitable.

EXPOSURE CRITERIA

Remedial movement has been assumed, for the purposes of this study, to be primarily a "life-saving" countermeasure; i.e., its purpose is to reduce the probability of death. Obviously, remedial movement can also be considered useful if it reduces the probability of injury. Although the relationship between radiation injury and exposure is controversial, some criteria are needed for analytical purposes. The following dose-effects criteria were selected somewhat arbitrarily for use in this study:

100r in less than two weeks - no illness,
200r in less than two weeks - a few people ill,
400r in less than two weeks - many ill, less than 50% mortality,
600r in less than two weeks - all ill, many deaths, few survivors.

These criteria, selected prior to the publication of the recommendations of the National Committee on Radiation Protection for emergency exposure2/, are in essential agreement with the Committee findings. The dose-effects cited above are approximately the same as those given for "brief, whole-body, gamma-ray" exposures (table 6.4, p. 70, of ref. 2). Since the above criteria cover exposure periods ranging from "brief" (a few seconds to four days) to two weeks, the effects should

be less than those stated above for the two-week exposures. In this sense, the criteria are conservative.

CALCULATIONS

The dose to people subjected to remedial movement consists of three components: 1) the dose received in the refuge before evacuation, 2) the dose received during the actual transfer, and 3) the dose received at the secondary location. To obtain an indication of the worth of remedial movement, the movement dose can be compared to the dose that would have been received if the person had chosen to remain in the refuge for, say, 14 days. The basic case studied herein was the movement in a vehicle from a refuge across the fallout area to an uncontaminated or decontaminated area. Only the first two dose components of the three cited above were calculated since the dose after movement would be negligible.

$$D_r \text{ (dose in refuge)} = d_f(t,t_a) \cdot I \cdot \frac{1}{P}$$

where $d_f(t,t_a)$ = dose factor, i.e., dose in an exposed location from time of fallout arrival to any given time t, based on a reference intensity of 1 r/hr at one hour. Different dose factors are used herein for three different fallout arrival times, t_a,

I = reference intensity or dose rate of the fallout radiation, i.e., r/hr, corrected to one hour after detonation,

P = protection factor of the refuge or shelter.

$$D_m \text{ (dose during movement)} = \left[d_f(t_3,t_a)-d_f(t_2,t_a)\right] \cdot I \cdot \frac{1}{P_v} \cdot C$$

where t_2 and t_3 = respectively the time movement is started and the time movement is completed (i.e., the time of exit from the contaminated area). Therefore, (t_3-t_2) is the travel time,

P_v = protection factor of the vehicle,

C = dose correction factor to compensate for the decrease of radiation intensity as the fallout area is traversed.

D_t (total remedial movement dose) = $D_r + D_m$.

CONDITIONS STUDIED

I (reference intensity, r/hr at 1 hour): 100, 300, 1000, 3000, 10,000 r/hr each for t_a = 1 hour, 6 hours, and 11 hours.

P (protection factor of refuge): 3, 6, 10, 20, 50.

P_v (protection factor of vehicle): 2.

C (fallout field transit correction): 1/2.

(t_3-t_2) (travel time): 1/4, 1/2, 1, 2, 3, 4 hours.

t_2 (go-time): was determined for various combinations of P and (t_3-t_2) on the basis of the equation:

$$t_2 = 0.6\ P\ (t_3-t_2).^*$$

However, since the dose predictions are dependent on knowledge of the reference radiation intensity, "go-time" was assumed never to be earlier than the time that fallout had ceased falling. These times were 1-1/2, 7, and 13 hours for fallout arrival times of 1, 6, and 11 hours, respectively. With the exception of the 1-1/2 hour cessation time, the "go-time" was

---

* This equation gives the "go-time" for which the sum of the shelter dose and the movement dose is a minimum. The equation was originally developed by Brooks et al[3] and adopted for operational use by the California Disaster Office[4].

rounded off to the nearest hour. These values are given in table 1.

The total number of computations was reduced by introducing limits based on the exposure criteria previously established. The limits are as follows: 1) if the refuge dose in 14 days is 100r or less, there is no need for remedial movement; 2) if the remedial movement dose, D_r+D_m, is greater than 600r, there is no obvious justification for remedial movement. Therefore, for cases in which either D_r or D_m is greater than 600r, no calculations were made.

FALLOUT DOSE DATA

Table 2 presents dose factors for the chosen arrival times. The numbers given are the dose in roentgens that will be received in an exposed location between the time of fallout arrival t_a and some later time t, for a reference radiation intensity of 1 r/hr*. The dose during fallout arrival was established by numerically integrating empirical intensity curves. The dose after the arrival period is based on intensity-time data derived for fission product mixtures plus induced activities.

RESULTS

The results of the computations are shown on figures 1, 2, 3, 4, and 5, which correspond to refuge protection factors of 3, 6, 10, 20, and 50, respectively. Each figure is subdivided into separate graphs for the three arrival conditions. The figures may be interpreted as follows. Referring to figure 1 for a protection factor of 3 and a 1-hour fallout arrival:

1. A 600r refuge dose (in 14 days) occurs when the reference intensity is about 520 r/hr. A 400r 14-day refuge dose occurs at a reference intensity of about 350 r/hr.

---

* Reference radiation intensity, often called standard intensity, is the dose rate obtained by extrapolating the dose rate at any time to that at one hour after detonation.

	P, protection factor				
t_3-t_2	3	6	10	20	50
1/4	0.45/1.5	0.9/1.5	1.5/1.5	3/3	7.5/8
1/2	0.9/1.5	1.8/2	3/3	6/6	15/15
1	1.8/2	3.6/4	6/6	12/12	30/30
2	3.6/4	7.2/7	12/12	24/24	60/60
3	5.4/5	10.8/11	18/18	36/36	90/90
4	7.2/7	14.4/14	24/24	48/48	120/120

First value - as calculated.

Second value - as rounded off or limited by fall-out cessation time of 1-1/2 hours.

Note: Values given apply to t_a=1 hour. For t_a=6 and 11 hours, t_2 was not less than 7 and 13, respectively.

Table 1. "Go-time," $t_2 = 0.6\ P\ (t_3-t_2)$

t (hr)	t_a=1	t_a=6	t_a=11	t (hr)	t_a=1	t_a=6	t_a=11
1.5	0.467	-	-	28	2.50	1.10	0.708
2	0.725	-	-	29	2.52	1.11	0.726
3	1.06	-	-	30	2.53	1.13	0.743
4	1.29	-	-	31	2.55	1.15	0.760
5	1.45	-	-	32	2.57	1.16	0.776
6	1.58	-	-	33	2.58	1.18	0.791
7	1.69	0.286	-	34	2.60	1.19	0.806
8	1.78	0.375	-	35	2.61	1.21	0.820
9	1.86	0.452	-	36	2.63	1.22	0.834
10	1.92	0.519	-	37	2.64	1.24	0.847
11	1.98	0.579	-	38	2.65	1.25	0.860
12	2.04	0.632	-	39	2.66	1.26	0.872
13	2.08	0.679	0.291	40	2.68	1.27	0.885
14	2.12	0.718	0.329	41	2.69	1.28	0.896
15	2.16	0.755	0.367	42	2.70	1.30	0.908
16	2.20	0.792	0.404	43	2.71	1.31	0.919
17	2.23	0.827	0.439	44	2.72	1.32	0.930
18	2.26	0.859	0.471	45	2.73	1.33	0.940
19	2.29	0.889	0.501	46	2.74	1.34	0.950
20	2.32	0.918	0.529	47	2.75	1.35	0.960
21	2.35	0.944	0.556	48	2.76	1.36	0.970
22	2.37	0.969	0.581	49	2.77	1.37	0.980
23	2.40	0.993	0.605	50	2.78	1.38	0.989
24	2.42	1.02	0.628	51	2.79	1.39	0.998
25	2.44	1.04	0.649	52	2.80	1.40	1.01
26	2.46	1.06	0.670	1 wk	3.27	1.87	1.48
27	2.48	1.08	0.689	2 wk	3.50	2.10	1.71

Table 2. Dose Factors d_f (t,t_a), i.e., Fallout Radiation Dose in Roentgens From Time of Arrival t_a, to Given Times t, Based on 1 r/hr Reference Intensity

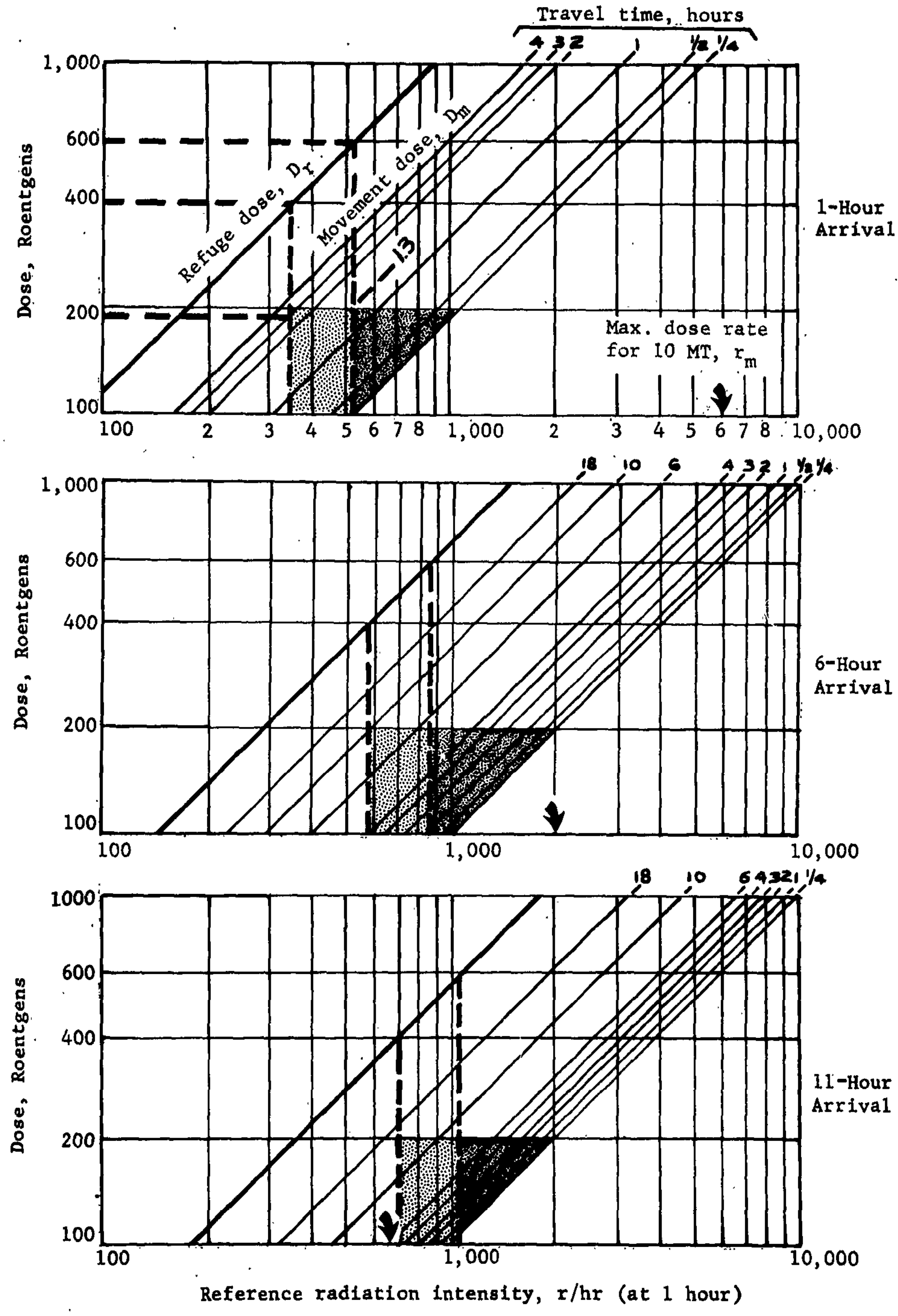

Figure 1. Remedial Movement and Refuge Exposures for Refuge Protection Factor of 3

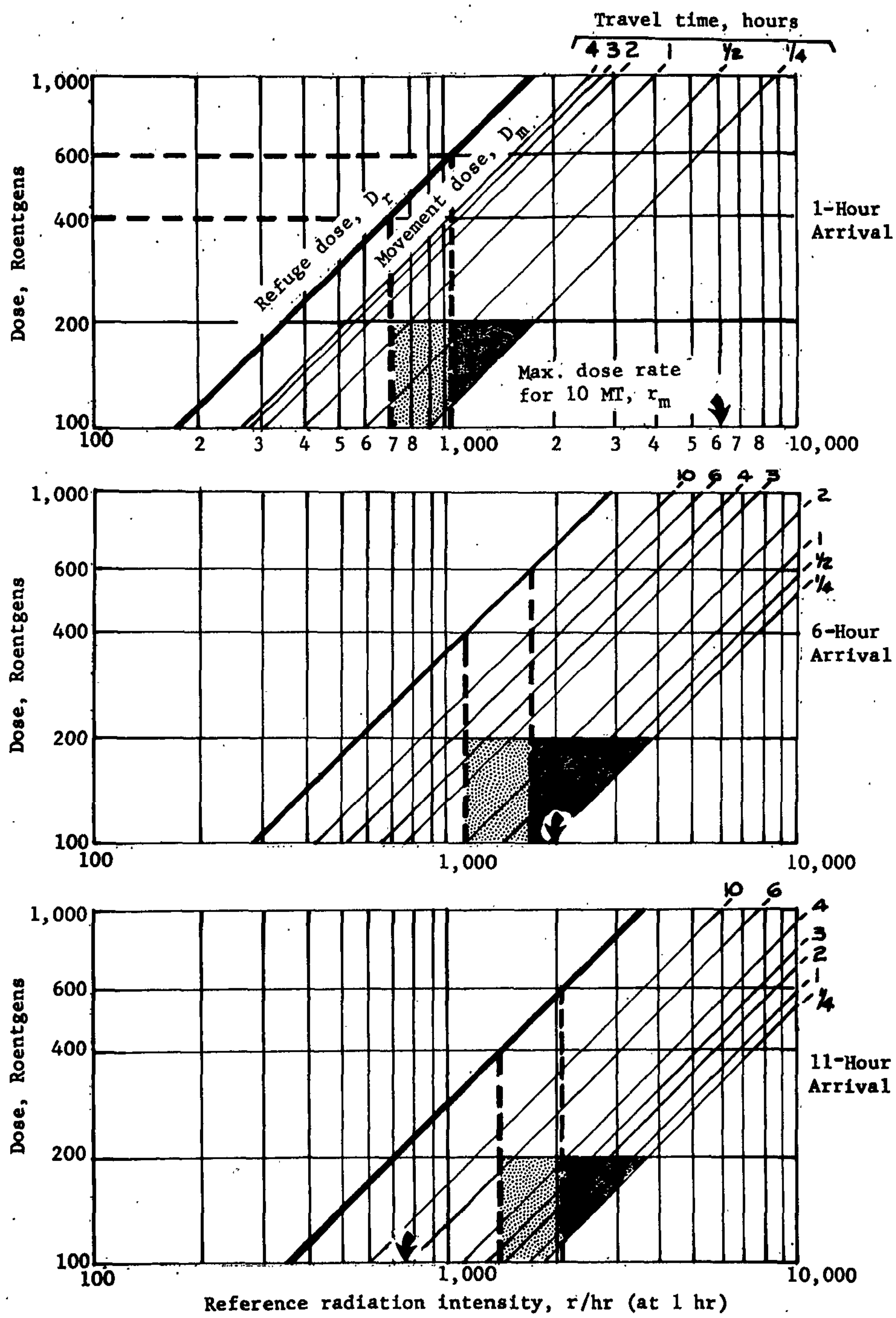

Figure 2. Remedial Movement and Refuge Exposures for Refuge Protection Factor of 6

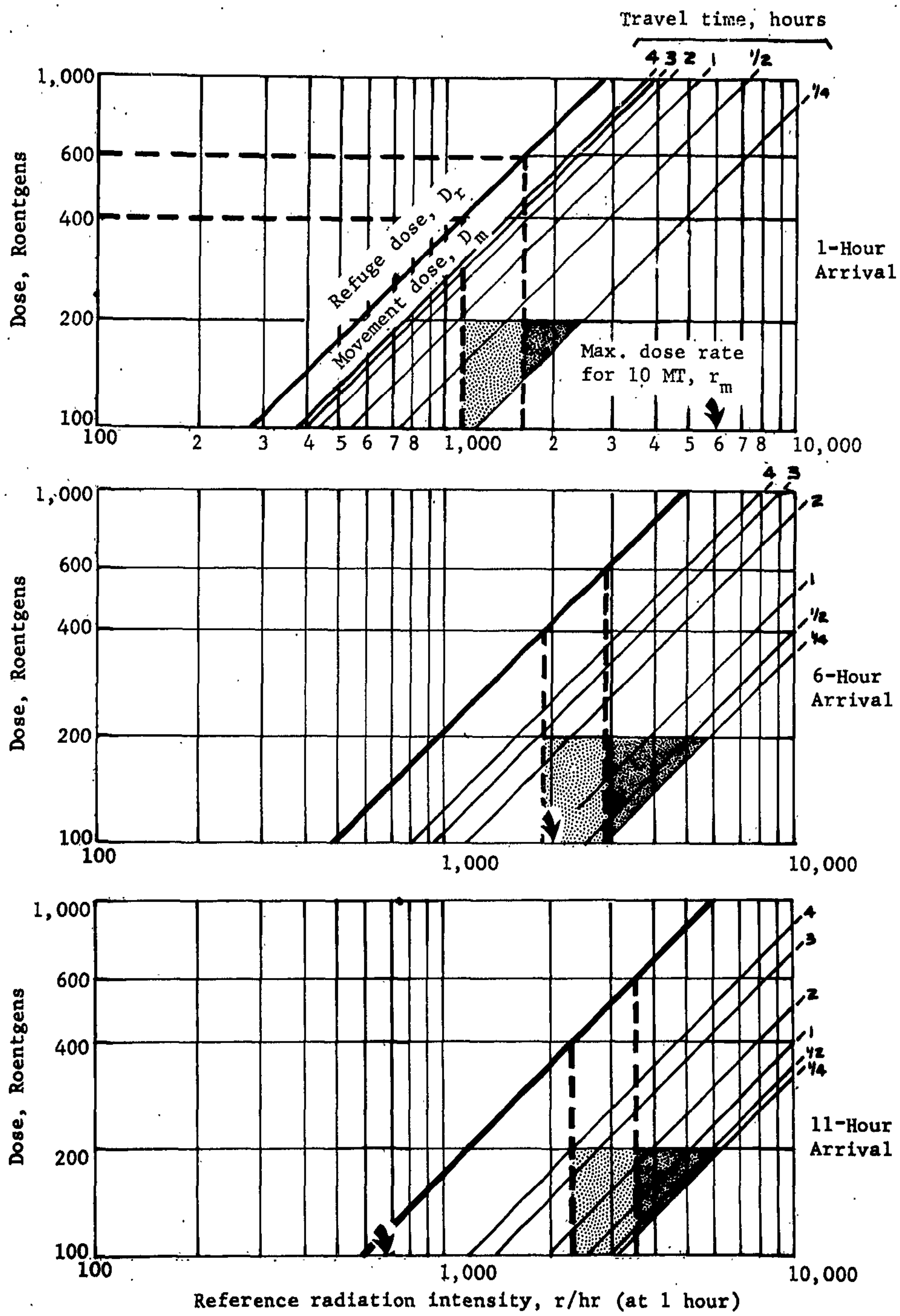

Figure 3. Remedial Movement and Refuge Exposures for Refuge Protection Factor of 10

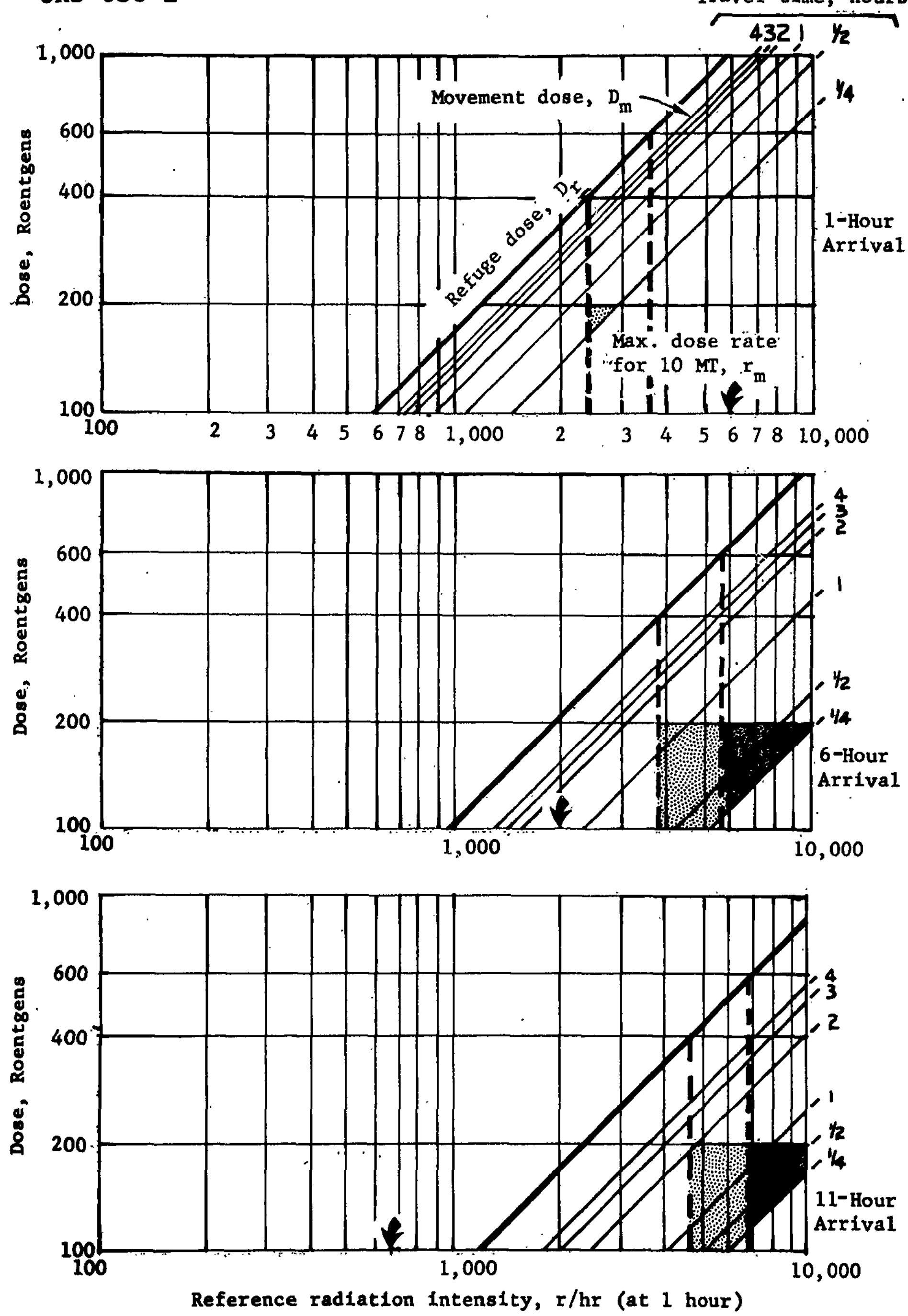

Figure 4. Remedial Movement and Refuge Exposures for Refuge Protection Factor of 20

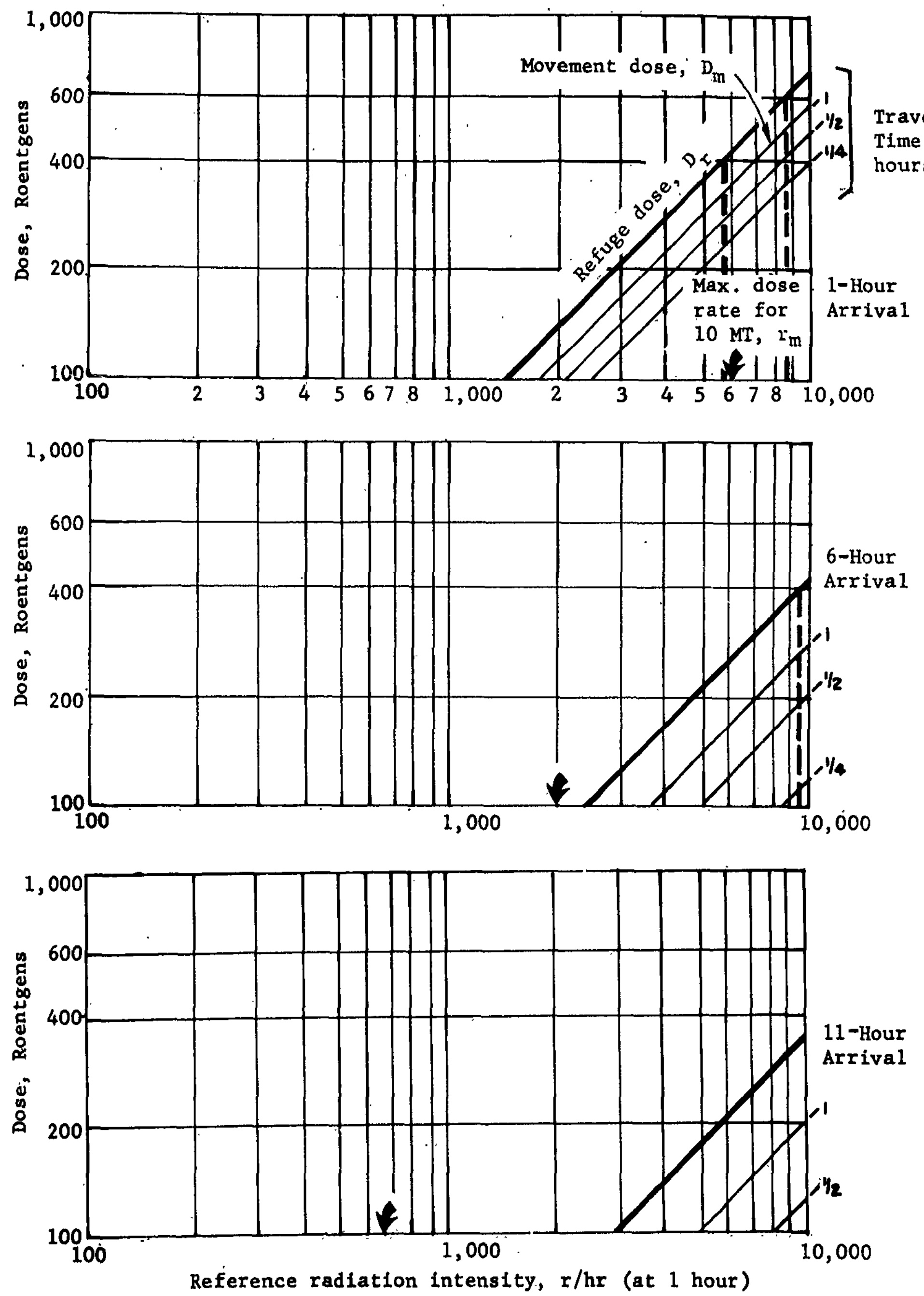

Figure 5. Remedial Movement and Refuge Exposures for Refuge Protection Factor of 50

2. If remedial movement is implemented for the 350 r/hr case (i.e., 400r refuge dose), and the travel time is estimated to be 3 hours, the total remedial movement dose would be about 190r.

3. If the reference intensity were 520 r/hr (i.e., 600r refuge dose), the travel time would have to be 1.3 hours or less, to keep the exposure during movement below 200r.

In the judgement of the author, the shaded areas on the figures indicate the primary payoff conditions.

1. The darkly shaded area indicates conditions in which a refuge dose of 600r or greater (i.e., high mortality) is reduced to a remedial movement dose of 200r or less. On figure 1, Arrival Time of One Hour, the travel time cannot exceed 1.3 hours if the above payoff condition is to be obtained.

2. The lightly shaded area indicates conditions where potentially high mortality exposures in the shelter are reduced to 200r or less by remedial movement. In the case on figure 1, travel time must be about 3.3 hours or less.

Obviously, other payoff conditions exist. However, the ones chosen appear to be the ones deserving first priority.

Arrowheads are also shown on the figures indicating "Maximum Dose Rate for 10 MT." These have been inserted to indicate the order of magnitude of the maximum reference intensity that might be associated with the various arrival times. This information was derived from Pugh and Galliano[6/] which tabulates the maximum downwind extent (in miles) of specified reference radiation dose rates. These values are given as functions of weapon yield, wind velocity, and effective wind shear. The downwind extent of various radiation intensities for an effective shear of 0.1 knot (per 1000-foot altitude) was plotted on figure 6. A greater shear produces lesser reference intensities at any given distance and wind velocity. The plotted values are related to a 100 percent

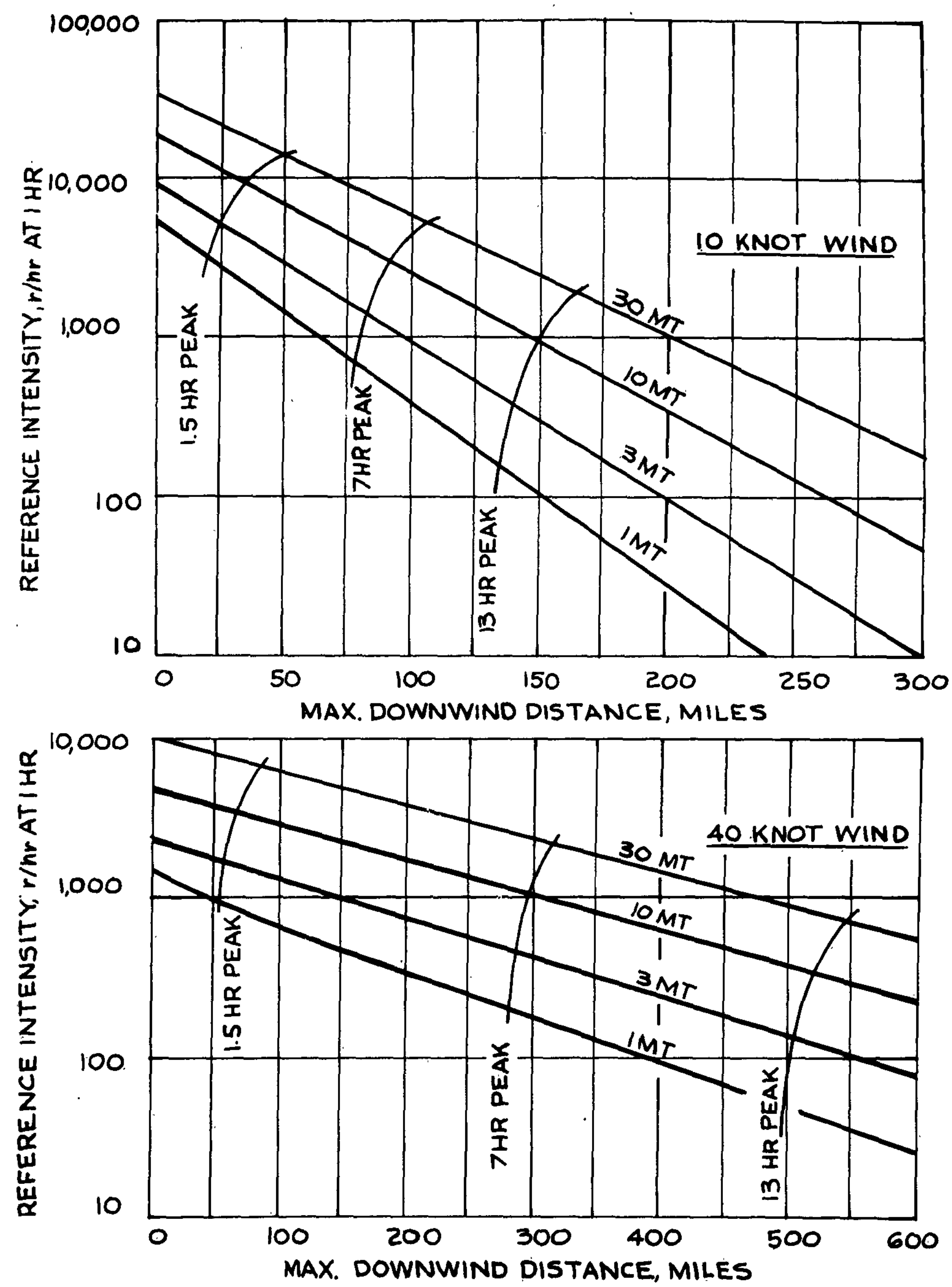

Figure 6. Maximum Possible Reference Intensities Appropriate to Different Arrival Times, Yields, and Wind Velocities

fission yield so that suitable corrections should be made for more realistic devices. Also plotted on figure 6 are the down-wind distances relatable to the assumed times of peak intensity (essentially time of arrival of fallout) and the assumed wind velocities. The distances for the same arrival time also vary with yield because of the differences in initial cloud diameter. The intersections of the plotted curves indicate on the ordinate the maximum reference intensity related to a certain arrival time, weapon yield, and wind velocity. Maximum values occur with a 30-megaton yield, 10-knot wind, and effective fallout shear of 0.1 knot. Reasonable maximum values are assumed to be defined by a 10-megaton yield detonation, with two-thirds of the yield due to fission. On this basis, the maximum feasible reference intensities for different arrival times are as follows:

Maximum Feasible Reference Intensity, r/hr

	10-MT detonation - 10-knot wind	
Arrival Time	100% fission	67% fission
1 hr (1.5-hr peak)	9000	6000
6 hr (7-hr peak)	3000	2000
11 hr (13-hr peak)	1000	670

The maximum intensities tend to indicate limits of the problem for the later arrival times. For instance, figure 2 (protection factor = 6) for an 11-hour arrival indicates that refuge doses of greater than 200r may not occur. Because of the uncertain nature of this limit, it should be used only as a guide.

CONCLUSIONS

Within the limitations imposed by the conditions of the study, certain general conclusions can be drawn from inspection of the figures:

1. As might be expected, the maximum opportunities for pay-off are related to lower protection factors, i.e., less than 10.

2. Maximum payoff conditions are related to fallout arriving earlier than eleven hours.

3. Maximum payoff conditions generally involve reference radiation intensities of 350 r/hr or greater, with the upper limit of about 2000 r/hr.

4. For 1-hour arrivals, the maximum allowable travel time for maximum payoff is about 1.3 hours.

RECOMMENDATIONS

The above conclusions indicate that remedial movement is technically feasible in a variety of radiological situations. However, additional studies are needed to determine the impact of fallout arrivals between one and six hours.

The development of simple decision procedures and operational planning guides are also needed to determine the operational practicality of remedial movement.

LIST OF REFERENCES

1. California Disaster Office, Planning Guide, Radiological Defense Annex, pp 1-4.

2. National Committee on Radiation Protection and Measurement, Exposure to Radiation in an Emergency, Report No. 29, January 1962.

3. Brooks, F. C., et al. Radiological Defense Planning Guide, Technical Operations, Inc. Report No. TOI-58-26, 31 July 1958.

4. Control of Exposure Using Shelter and Movement, California Disaster Office, Radef Division, May 1961.

5. Doughty, D. J. and D. C. Kleinecke, A Simplified Time-Dependent Gamma-Ray Spectrum for Fallout. University of California, Institute of Engineering Research, Series 2, Issue 26, 15 August 1959.

6. Pugh, G. E. and R. J. Galliano. An Analytic Model of Close-in Deposition of Fallout for Use in Operational-Type Studies, Weapons Systems Evaluation Group, WSEG Research Memorandum No. 10, 15 October 1959.

DISTRIBUTION LIST

62 Office of Civil Defense, DOD
Pentagon, Washington, D.C.
ATTN: Director for Research

3 Army Library
Civil Defense Unit
Washington 25, D.C.

1 Assistant Secretary of the Army (R&D)
Washington 25, D.C.
ATTN: Assistant for Research

1 Chief of Naval Research (Code 104)
Department of the Navy
Washington 25, D.C.

1 Chief of Naval Operations (OP-07T10)
Department of the Navy
Washington 25, D.C.

1 Chief, Bureau of Naval Weapons (Code RRRE-5)
Department of the Navy
Washington 25, D.C.

1 Chief, Bureau of Medicine and Surgery
Department of the Navy
Washington 25, D.C.

1 Chief, Bureau of Supplies & Accounts (Code L12)
Department of the Navy
Washington 25, D.C.

1 Chief, Bureau of Yards & Docks
Office of Research (Code 74)
Department of the Navy
Washington 25, D.C.

1 U.S. Naval Civil Engineering Laboratory
Port Hueneme, California

20 Defense Documentation Center
Cameron Station
Alexandria, Virginia

1 Advisory Committee on Civil Defense
National Academy of Sciences
2101 Constitution Avenue, N.W.
Washington 25, D.C.
ATTN: Mr. Richard Park

2 Chief, Bureau of Ships (Code 335)
Department of the Navy
Washington 25, D.C.

1 Chief, Bureau of Ships (Code 203)
Department of the Navy
Washington 25, D.C.

1 Coordin, Marine Corps
Landing Force
Development Activities
Quantico, Virginia

1 Dr. Wayne Bell
General Dynamics Corp.
P.O. Box 5
Old San Diego Station
San Diego 10, California

1 Dr. Eric Clarke
Technical Operations Inc.
Burlington, Massachusetts

Distribution List (Cont'd)

1 Dr. Carl F. Miller
Stanford Research Institute
Menlo Park, California

1 Cdr. W. J. Christensen
Naval Civil Engineering
Laboratory
Port Hueneme, California

1 Dr. J. Laurence Kulp
Isotopes Incorporated
123 Woodlawn Avenue
Westwood, New Jersey

1 Dr. Louis Gavantman
Naval Radiological Defense
Laboratory
San Francisco, California

1 Mr. Joseph Maloney
Nuclear Defense Laboratory
Army Chemical Center
Edgewood, Maryland

1 Dr. Wayne A. McRae
Ionics Incorporated
152 6th Street
Cambridge, Massachusetts

1 Mr. R. P. Schmidt
U.S. Army Material Office
Directorate of Research &
Development
Fort Belvoir, Virginia

1 Dr. Edgar Parsons
Research Triangle Institute
P.O. Box 490
Durham, North Carolina

1 Mr. C. Herbert Wheeler
Curtiss-Wright Incorporated
Caldwell, New Jersey

1 Mr. Olaf Fernald
Advance Research Inc.
19 Brook Road
Needham Heights 94, Mass.

1 Dr. Eugene Sevin
IIT Research Institute
10 West 35th Street
Chicago 16, Illinois

1 Dr. Paul Parrino
Public Health Service, DHEW
Washington 25, D.C.

1 Mr. Herman Kahn
Hudson Institute
Quaker Ridge Road
Harmon-on-Hudson, New York

1 Lt. Col. Converse R. Lewis
Office of the Surgeon General
Main Navy Building
Washington 25, D.C.

1 Dr. Frank Todd
Assistant to the Administrator
Agricultural Research
U.S. Department of Agriculture
Washington 25, D.C.

1 Col. Stanley J. Widenkaph
Hq. Medical R&D Command
Main Navy Building
Washington 25, D.C.

Distribution List (Cont'd)

1 Mr. Gordon E. McCallum
Water Supply & Pollution Control
Public Health Service, DHEW
Washington 25, D.C.

1 Mr. George W. Burke, Jr.
Div. of Water Supply & Pollution Control
Public Health Service, DHEW
Washington 25, D.C.

1 American Institute for Research
410 Amberson Avenue
Pittsburgh, Pennsylvania

1 Psychological Laboratories
University of Georgia
Athens, Georgia

1 Dr. Frederick Bellinger
School of Engineering
Georgia Institute of Technology
Atlanta, Georgia

1 Dr. W. Fulton Abercrombie
U.S. Public Health Service
Division of Health Mobilization
Washington 25, D.C.

1 Mr. Ken Kaplan
1811 Trousdale Avenue
United Research Services
Burlingame, California

1 Lt. Col. J. R. Bohannon
Air Force Office of Civil Engineering
Washington 25, D.C.

1 Dr. Frank Parker
Health Physics Division
Oak Ridge National Laboratory
Oak Ridge, Tennessee

1 PARM Project
7th Floor
1424 16th St., N.W.
Washington, D.C.

1 Dr. Joseph Coker
Office of Emergency Planning
Washington 25, D.C.

1 Dr. Ray Edwards
Nuclear Science & Engineering Corporation
P.O. Box 10901
Pittsburgh 36, Pennsylvania

1 Mr. H. Malcolm Childers
708 North West Street
Alexandria 14, Virginia

1 Technical Information Service
U.S. Atomic Energy Commission
Oak Ridge, Tennessee

1 Mr. Jim G. Terrell, Jr.
Radiological Health Division
U.S. Public Health Service, DHEW
Washington 25, D.C.

1 Dr. Werner N. Grune
Professor of Civil Engineering
Merrimack College
North Andover, Mass.

Distribution List (Cont'd)

1 Mr. Walter Wood
Dikewood Corp.
4805 Menaul Blvd, N.E.
Albuquerque, New Mexico

1 U.S. Atomic Energy
Commission
Hdq. Reports Library
G-017
Germantown, Maryland

1 Commander, Field Command
Defense Atomic Support Agency
Sandia Base
Albuquerque, New Mexico

1 Dr. Morgan Seal
U.S. Public Health Service
Box 684
Las Vegas, Nevada

2 Defense Logistics Studies
Information Exchange
U.S. Army Logistics Management Center
ATTN: Col. L. A. Robbins
Fort Lee, Virginia

1 NASA Headquarters
Office of Advanced Research
& Technology
1512 H Street, N.W.
Washington, D.C.

1 Commanding General
Combat Developments Command
Materiel Requirements Div.
Fort Belvoir, Virginia

1 Assistant Secretary of the
Air Force (R&D)
Room 4E968
The Pentagon
Washington 25, D.C.

1 Advanced Research Projects
Agency
Department of Defense
The Pentagon
Washington 25, D.C.

1 Dr. Vincent Schultz
Division of Biology and
Medicine
U.S. Atomic Energy Commission
Washington, D.C.

1 Dr. Arnold H. Sparrow
Biology Department
Brookhaven National
Laboratory
Upton, Long Island, New York

1 Dr. John D. Spikes
Department of Experimental
Biology
University of Utah
Salt Lake City, Utah

1 Dr. Wm. S. Osborn, Jr.
Institute of Arctic and
Alpine Research
University of Colorado
Boulder, Colorado

Distribution List (Cont'd)

1 Mr. Edward G. Struxness
Deputy Director
Health Physics Division
Oak Ridge National Laboratory
Oak Ridge, Tennessee

1 Department of Sanitary
Engineering
Walter Reed Army Institute
of Research
Washington, D.C. 20012

1 Naval Command Systems Support
Agency
U.S. Naval Station
Washington Navy Yard Annex
Building 196
Washington 25, D.C.
ATTN: N. L. Richardson, Code 22

1 Lt. Morgan S. Ely
Navy Training Publications Center
Navy Yard Annex
Washington, D.C. 20390